

## **General Disclaimer**

### **One or more of the Following Statements may affect this Document**

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.
- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.
- This document is paginated as submitted by the original source.
- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

(NASA-CR-147143) AETHER DRIFT AND THE  
ISOTROPY OF THE UNIVERSE Semiannual  
Progress Report, 1 Oct. 1975 - 31 Mar. 1976  
(California Univ.) 31 p HC \$4.00 CSCI 03B

N76-23116

Unclas  
25255  
G3/90

# SPACE SCIENCES LABORATORY

## AETHER DRIFT AND THE ISOTROPY OF THE UNIVERSE

Semiannual Progress Report

10/1/75 - 3/31/76

NASA Grant No. NSG-2125

NASA Technical Officer:  
R.W. Cameron, NASA Ames

Principal Investigator  
Richard A. Muller ✓

Co-experimenters  
Luis W. Alvarez  
Andrew Buffington  
Marc V. Gorenstein  
Charles D. Orth  
Stephen M. Pollaine  
George F. Smoot

15 April 1976



UNIVERSITY OF CALIFORNIA, BERKELEY 94720

UCB SSL-Series 17- Issue-25

## "AETHER DRIFT" AND THE ISOTROPY OF THE UNIVERSE:

### A search for anisotropies in the primordial black-body radiation

#### ABSTRACT:

This experiment will detect and map the large-angular-scale anisotropies in the 3°K primordial black-body radiation with a sensitivity of  $2 \times 10^{-4} \text{°K}$  and an angular resolution of about  $10^\circ$ . It will detect the motion of the earth with respect to the distant matter of the Universe ("Aether Drift"), and will probe the homogeneity and isotropy of the Universe (the "Cosmological Principle"). The experiment will use two Dicke radiometers, one at 33 GHz to detect the cosmic anisotropy, and one at 54 GHz to detect anisotropies in the residual oxygen above the detectors. An upper hatch for the NASA-AMES Earth Survey Aircraft (U-2) is currently being modified to accept the dual-radiometer system. The system will be installed in the aircraft in the spring of 1976. Initial engineering flights will be done in a piggy-back mode, while the aircraft is on other missions. Data taking flights will take place later in the year. A few hours of observation should be sufficient to detect an anisotropy. Several flights spread out over a year will be necessary to understand the anisotropy in detail.

#### CONTENTS:

|                        |    |
|------------------------|----|
| I. INTRODUCTION        | 1  |
| II. THEORY             | 4  |
| III. EXPERIMENT STATUS | 11 |
| IV. BUDGET             | 19 |
| V. BIBLIOGRAPHIES      | 21 |

## I. Introduction

The earth is bathed in an apparently universal  $3^{\circ}\text{K}$  microwave radiation from space. Its existence is the strongest evidence we have in support of the Big Bang theory of the Universe, and its observed isotropy to one part in  $10^3$  is the strongest evidence we have in support of the Cosmological Principle (the speculation that the Universe is isotropic and homogeneous on a large scale). Anisotropies smaller than one part in  $10^3$  are expected, but never have been unambiguously observed. For the past two years we have been designing and constructing a radiometer system to detect and map these small anisotropies with a sensitivity of  $2 \times 10^{-4}\text{K}$ , an order-of-magnitude better than that of previous experiments. The study of the anisotropies observable with this sensitivity will provide a unique probe of the nature of the universe.

The experiment uses two twin-horn Dicke radiometers, flown to an altitude of 65,000 feet in the modified upper hatch of the NASA-AMES Earth Survey Aircraft (U-2). The cosmic anisotropy will be measured with the 33 GHz radiometer, whose frequency is in the window between galactic synchrotron emission and atmospheric oxygen emission. Background anisotropies from oxygen and residual tilt to the aircraft will be measured by the 54 GHz radiometer. Each radiometer has two horn antennas, pointing in opposite azimuthal directions but  $30^{\circ}$  from the zenith (See figure 1 and 2). A parametric amplifier is switched between the two antennas at 100 Hz in order to make a comparison between the two regions of the sky. This fast switching eliminates  $1/f$  noise due to amplifier drift. The two antennas are physically interchanged every two minutes in order to cancel any residual anisotropies between the horns. Every half-hour or so the airplane will reverse its direction, to detect and cancel anisotropies due to the



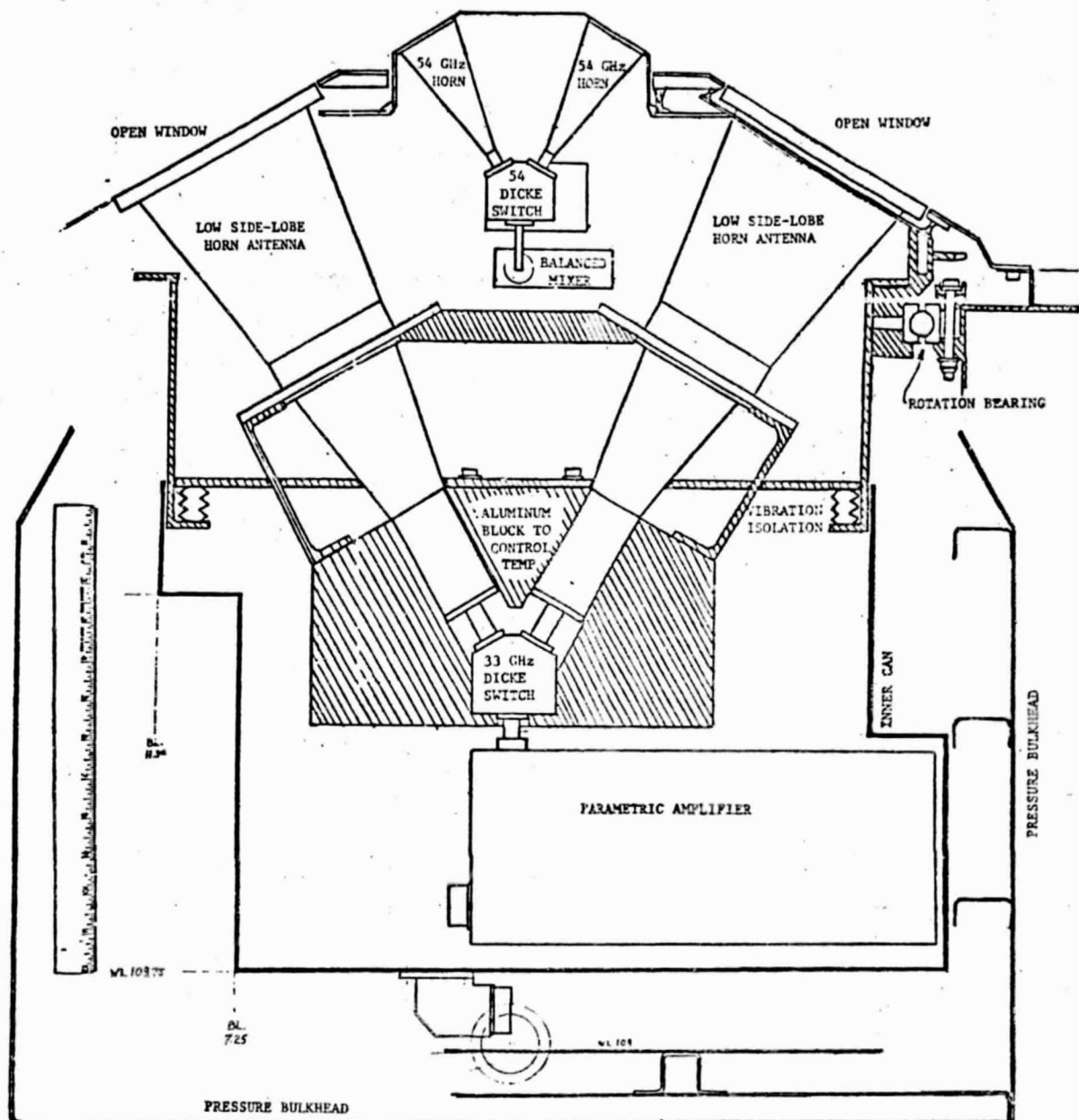


Figure 1. Cross-sectional view of the experimental apparatus, as it will be installed in the aircraft.

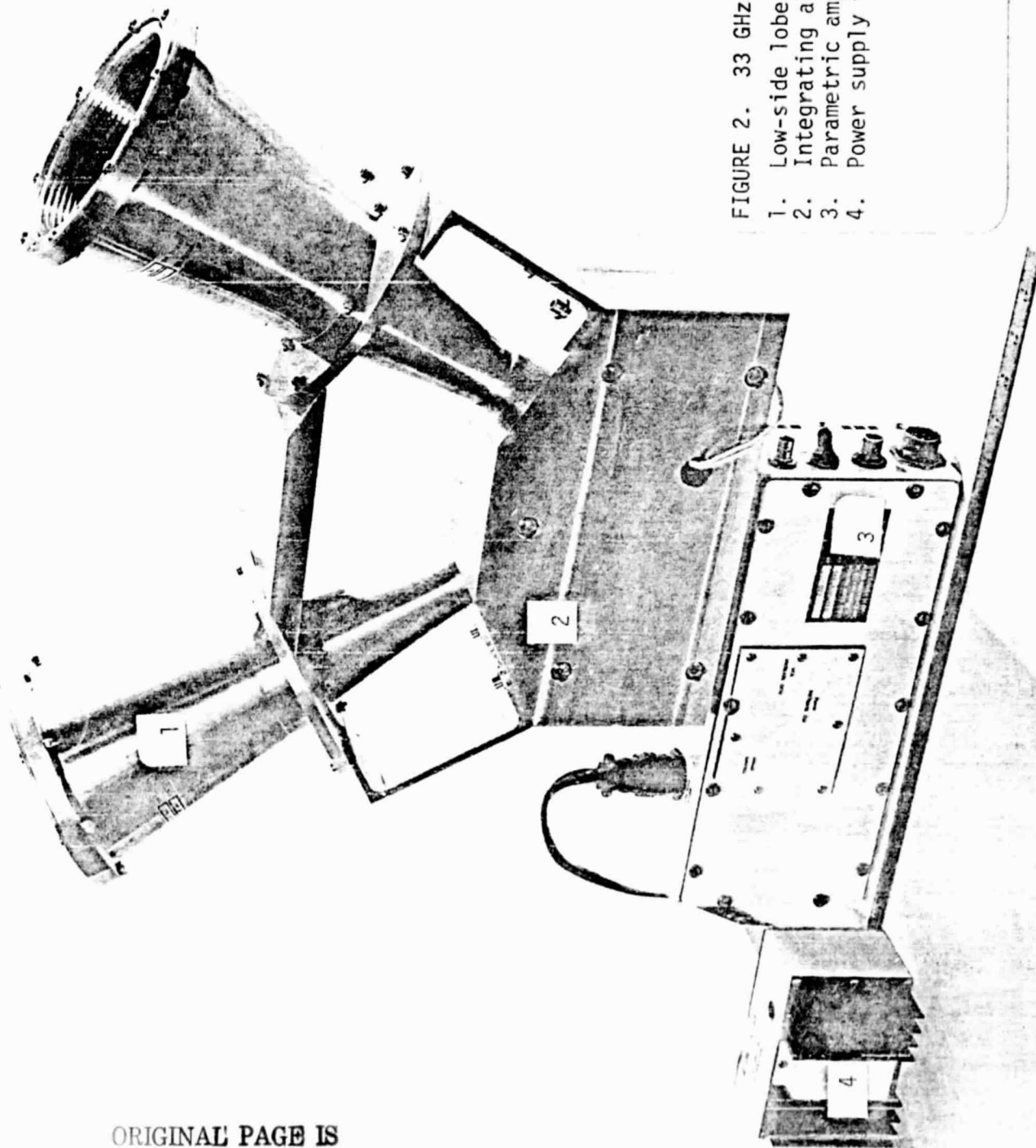


FIGURE 2. 33 GHz Receiver

1. Low-side lobe antennas
2. Integrating aluminum block
3. Parametric amplifier receiver
4. Power supply for Gunn Diode oscillator

ORIGINAL PAGE IS  
OF POOR QUALITY

aircraft. And, for the "Aether Drift" measurement, the earth changes its direction of revolution around the sun every six months, a reversal shift that our instrument will be sensitive enough to detect.

## II. Theory of the 3°K radiation and expected anisotropies

In 1965, Penzias and Wilson found an unexpectedly large background in their 7 cm microwave receiver. Many workers have since confirmed the existence of this background, covering a range in wavelengths from several millimeters to many centimeters. The figure below shows the measurements, together with a 2.7°K black-body Planck distribution. Also shown in the figure are intensities indirectly deduced from measurements of the absorption spectra of cyanogen molecules around nearby stars, covering short wavelengths absorbed by the earth's atmosphere.

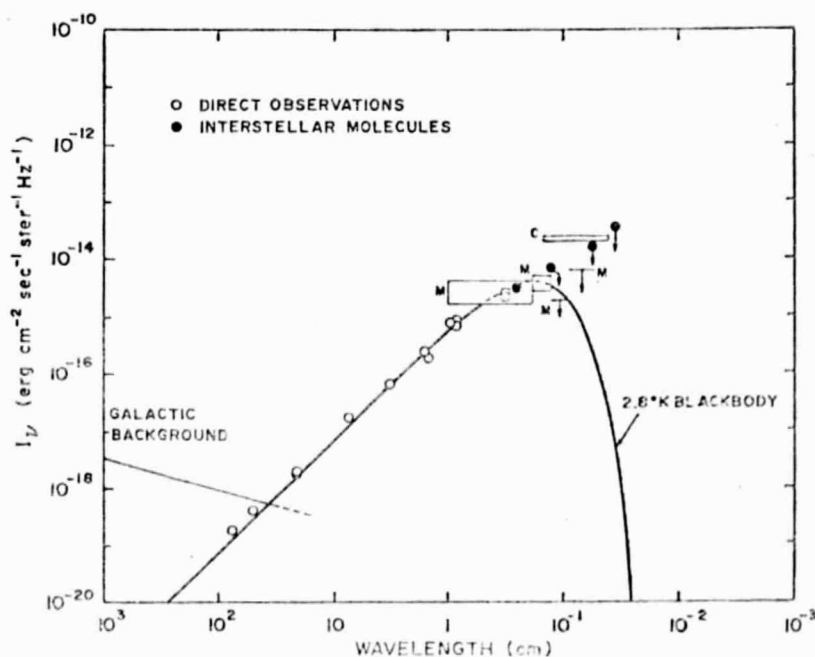


Figure 2. Measurement of the microwave background. (Taken from P. Thaddeus, *Ann. Rev. Astron. and Astrophys.* 10, 305 (1972)).

The best data in the millimeter region as of 1973 (Muehlner and Weiss, Phys. Rev. C, 7, (1973)) marked with the letter M, clearly showed the expected turnover. Recent measurements at Berkeley (D. Woody, J. Mather, N. Nishioka, P. Richards, Phys. Rev. Lett. 34, 1036 (1975)) have verified this turnover in detail. The measurements are all consistent with a black-body shape for the radiation. A number of measurements have also been made of the directionality of this radiation: no significant departure from isotropy has ever been seen, down to an accuracy of about one tenth of a percent.

Most cosmologists take this radiation to be a relic from past epochs when our universe was much hotter and denser than it is now. Indeed, the presence of the black-body radiation provides the strongest evidence to date for such a "Big Bang" origin of the Universe. In these early epochs the high temperature and densities kept almost all matter in an ionized state. Free electrons provided the thermal coupling between radiation and matter. When the expanding Universe had cooled to approximately  $4000^{\circ}\text{K}$ , these electrons became bound into atoms. At this point the radiation decoupled from the matter, and the Universe became essentially transparent to the thermal radiation. The expansion of the Universe then red-shifted the radiation down to its present-day temperature of  $2.7^{\circ}\text{K}$  without altering its black-body shape.

The black-body radiation we observe now was originally radiated from a sphere of radius  $2 \times 10^{10}$  light years. Until neutrino astronomy becomes practical, these black-body photons provide our deepest probe into the past history of our Universe. At the time the radiation decoupled from matter, atoms and molecules were just beginning to form. Condensation into stars and galaxies had presumably not yet begun. The isotropy of the black-body

radiation is the strongest evidence that the early Universe was isotropic and homogeneous when viewed on a large-size scale (the "Cosmological Principle").

When we observe an anisotropy of the black-body radiation, the angular size of the anisotropy will suggest the mechanism which generated it. Motion of our earth reference frame relative to the "rest frame" defined billions of years ago by the last-scattering of the black-body photons is one mechanism that could produce an anisotropy. This modern "Aether Drift" experiment will show that vector sum of all the various motions of the earth listed in Table I. According to Special Relativity (Peebles and Wilkinson, Phys. Rev. 174, 2168 (1968)), motion of an observer relative to the uniform black-body radiation leaves the distribution shape of the radiation the same, but alters the observed black-body temperature to

$$T(\theta) = \frac{T_0 \sqrt{1 - \beta^2}}{1 - \beta \cos \theta} \approx T_0 (1 + \beta \cos \theta)$$

where  $T_0 = 2.7^\circ\text{K}$ ,  $\beta$  is the velocity of the observer relative to the black-body rest frame and  $\theta$  is the angle between the observer's viewing direction and  $\beta$ . It is clear from Table I that earth rotation is negligible and that motion of the solar system in the galaxy dominates. Small as it is, the annual orbit of earth around the sun should be separately detectable by our experiment by taking data throughout a year, thus providing an extremely powerful cross-check of our entire procedure.

Other features of the Universe which generate anisotropy in the black body radiation yield more complicated angular dependences. For example, consider the possible rotation of the Universe as a whole. If the universe rotates with an angular velocity  $\omega$ , then objects a distance  $R$  from us, and at an angle  $\theta$  to the axis of rotation, will have a velocity  $v_\theta = \omega R \sin \theta$ ,

TABLE I: MOTIONS OF THE EARTH RELATIVE TO "REST" FRAME

| Source of Motion                              | Expected Velocity <sup>(a)</sup> | Anisotropy <sup>(b)</sup>   |
|---|----------------------------------|-----------------------------|
|   | (km/sec)                         | (°K)                        |
| 1. Earth Rotation                             | 0.46                             | $0.1 \times 10^{-4}$        |
| 2. Orbit around Sun                           | 29.8                             | $5.3 \times 10^{-4}$        |
| 3. Solar System in Galaxy                     | $270 \pm 40$                     | $(49 \pm 7) \times 10^{-4}$ |
| 4. Galaxy around Local Cluster                | $80 \pm 20$                      | $(14 \pm 4) \times 10^{-4}$ |
| 5. Total Solar System around<br>Local Cluster | $315 \pm 15$                     | $(57 \pm 3) \times 10^{-4}$ |
| 6. Local Cluster relative to<br>Black-Body    | ?                                | ?                           |

(a) Our source for velocities from 3-5 is D.W. Sciama, "Astrophysical Cosmology" pages 183-236, Proceedings of the International School of Physics Enrico Fermi, Course XLVII, Academic Press, New York, 1971.

(b) Calculated according to the formula  $\Delta T = T_{\max} - T_{\min} = 2T_o \beta$  where  $\beta = \text{velocity}/\text{velocity of light}$ . This formula gives the peak-to-peak amplitude of the anisotropy.

which, when added to its Hubble recessional velocity, yields a second order Doppler shift (due to time dilation) that depends on  $\theta$ . The variation should be axially symmetric, and its first order term (proportional to  $\cos(2\theta)$ ) would be easily distinguishable from Aether Drift. A detailed analysis by Collins and Hawking (Monthly Notices of the Royal Astronomical Society 162, 307 (1973)) shows that if the Universe rotated at a rate of once per  $10^{14}$  years, an anisotropy of  $10 \times 10^{-4} \text{ }^\circ\text{K}$  would result.

Detection of an overall rotation of the universe would be of great philosophical and cosmological importance. According to Mach's Principle, the existence of local inertial frames is caused by the mass of the distant galaxies, implying that the apparent rotation of the universe is zero. A discovery of non-zero rotation (which is allowed by General Relativity) would cast the entire Machian philosophy of matter and space-time into doubt.

Inhomogeneities in the matter distribution or in the expansion of the Universe should likewise lead to an anisotropy of the black body radiation. Although these might in principle give a  $\cos(2\theta)$  term which would be confused with spin, it is much more likely instead that they would yield higher order terms. Most cosmologists believe that an experiment an order to magnitude more sensitive than previous experiments is bound to detect such an inhomogeneity. Such inhomogeneities have been related, in certain theories, to the existence of the observed super-clusters of galaxies.

In some of these theories the Universe was initially completely inhomogeneous. The approximate homogeneity we now observe came about by the transport of energy and momentum that occurred early in the Big Bang. There are limits on the angular scale size of regions which could have

been isotropized this way: a given region of space could not have received any homogenizing signal from further away than the distance light could travel between the time of the Big Bang and the time of the decoupling of radiation and matter.

Weinberg has calculated the angular size of isotropized regions in the sky which could have been generated this way ("Gravitation and Cosmology: Principles and Applications of the General Theory of Relativity", Wiley, New York, 1972, page 525. He reports that isotropy larger than just a few degree of angle in the sky requires a primordial homogeneity.\* A good sky map, with the temperature of the black-body radiation measured with fractional millidegree temperature accuracy in  $15^0$  angular bins might in fact show such residual anisotropies, thereby disclosing information about the size of the density homogeneity in the early universe, even before matter and radiation were uncoupled.

Most other sources of anisotropy should result in an angular scale too small for us to observe with this experiment (planned resolution  $15^0$ ), but might conceivably occur with a larger than expected scale. Such small-scale anisotropies could be due to inhomogeneities in the primordial plasma, or nascent galaxies, or they might be the first indication of discrete sources. Such emission anisotropies would appear as bright spots on the sky. Dark spots could also occur due to the absorption of some of the black-body radiation by large objects along the line of sight. A high density of energetic electrons in galactic clusters might attenuate the

---

\* For the case of an ionized intergalactic medium providing the mass to close the universe gravitationally this size grows to perhaps 1/10 of the sky, since the uncoupling of matter and radiation then took place at a much later time.



black-body radiation, by scattering it to higher frequencies. Such a cloud of electrons and their associated protons could help provide the mass needed for gravitational binding of galactic clusters.

The following table summarizes the possible causes of an inhomogeneity in the black-body radiation, and states the features of its angular distribution which would help distinguish it.









TABLE II: SOURCES OF ANISOTROPY AND THEIR ANGULAR DISTRIBUTIONS

|                                  |   |
|----------------------------------|---|
| Aether Drift - motion around sun | $\cos\theta$ ; amplitude varies<br>(sinusoidally) during a year |
| Aether Drift - motion of galaxy  | $\cos\theta$  |
| Spin of Universe                 | $\cos(2\theta)$ although higher<br>order terms possible         |
| Primordial Inhomogeneities       | $\cos(n\theta)$ , $n$ probably large                            |
| Other Inhomogeneities            | correlated position in sky<br>with suspected source             |

### III. Experiment Status

All the instrument hardware now exists and has been installed in the modified U-2 upper hatch. We are now in the process of checking out the equipment and correcting several mechanical and electrical problems discovered when the instrument was installed in the hatch. In the following schedule, the items with the check marks have been completed.

#### Experiment Fabrication and Check Out Schedule

| Activity   | Feb  | Mar   | Apr   | May   | Jun |
|--|--|---|---|---|-----|
| Ship bearing clamp to Lockheed   |   |   |   |   |     |
| Ship rotation system parts for installation on hatch                               |  |   |   |   |     |
| Ship all remaining parts and instrument for installation in hatch and pressure can |  |  |   |   |     |
| Test of system at Lockheed   |  |   |    |   |     |
| Equipment returns from Lockheed  |  |   |   |   |     |
| Check out of instrument  |  |  |  |   |     |
| First Engineering Flight   |  |   |   |  |     |

The instrument has been designed so that it is compatible with several others that fly regularly on the U-2's so that the engineering flight can be made piggyback without interference to the primary mission.

### Instrument Status

The fabrication and subsystem test phase is completed and we are presently in the system integration and check out phase. We are now working on such system areas as (1) r.f. shielding, (2) ground loop and, (3) vibration isolation. With the help of NASA-AMES we conducted a test run of our prototype radiometer (without the parametric amplifier receiver) while it was strapped in the U-2 equipment bay. The U-2 was operated both on external power and with its engine running and all systems on internal power. We made checks for r.f. and other electrical interference. We also observed the ground vibration spectrum; Lockheed has measured the vibration spectrum to be somewhat different in flight.

#### A) The 33 GHz Radiometer

The basic components are shown in the two accompanying photographs. The two antennas and ferrite switch are imbedded in the large aluminum block for thermal and also mechanical reasons. There are also temperature sensors to measure the difference between the antennas along their length. The receiver - the parametric amplifier, mixer, IF amplifiers, and associated electronics - is mounted in a box which is very delicately temperature controlled. The phase sensitive detector, ferrite switch driver, ideal integrator and noise monitor are now shown but are in their own separate r.f. shielded boxes.

#### B) The Atmospheric Monitor (54 GHz Radiometer)

All the atmospheric monitor components are completed and mounted. The photograph included here shows the receiver before it was assembled for mounting. The atmospheric monitor has its own separate antennas and ports. The atmospheric monitor looks through teflon windows while the 33 GHz antennas look through openings in the hatch. We have devised an

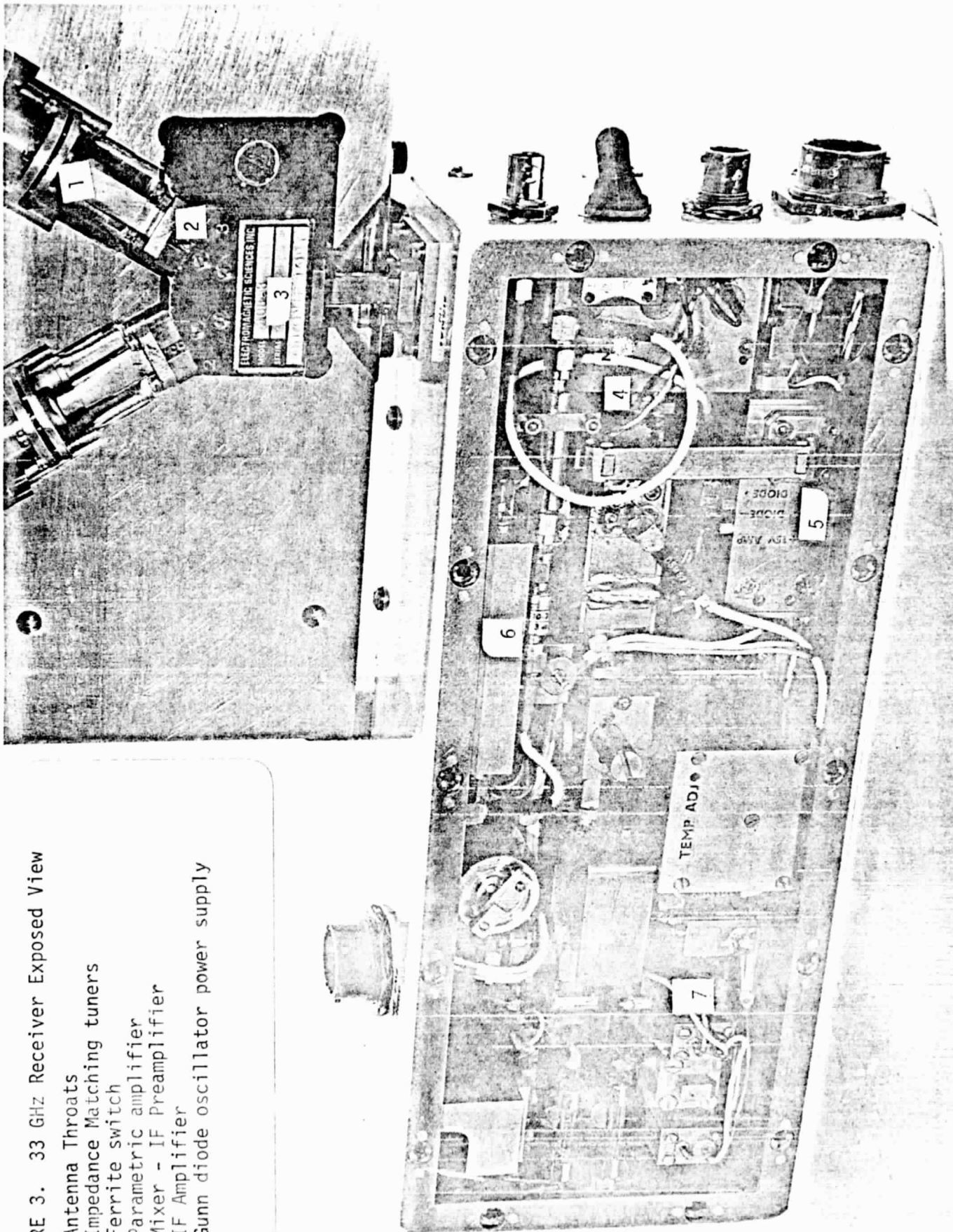


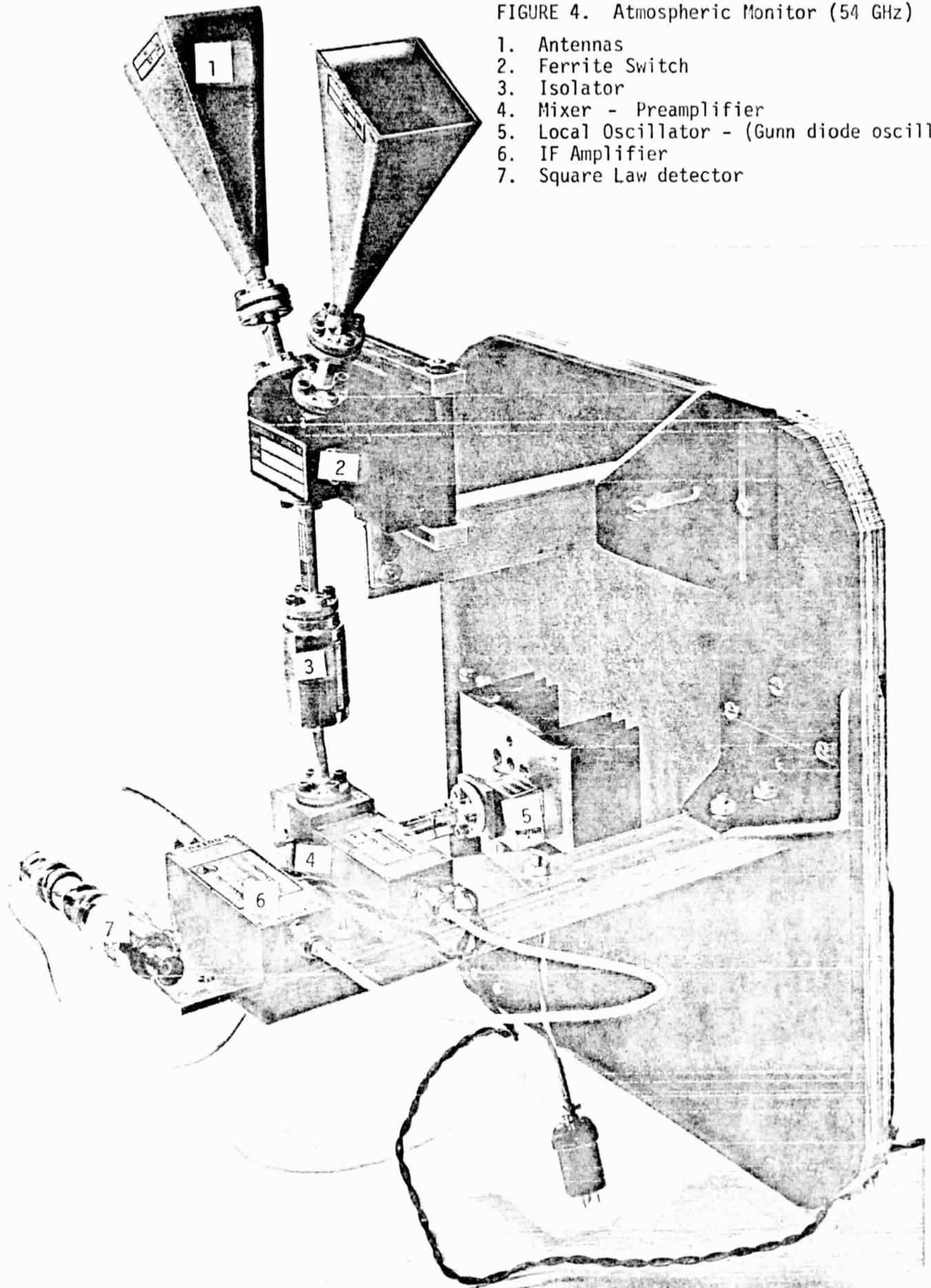
FIGURE 3. 33 GHz Receiver Exposed View

1. Antenna Throats
2. Impedance Matching tuners
3. Ferrite switch
4. Parametric amplifier
5. Mixer - IF Preamplifier
6. IF Amplifier
7. Gunn diode oscillator power supply

ORIGINAL PAGE IS  
OF POOR QUALITY

FIGURE 4. Atmospheric Monitor (54 GHz)

1. Antennas
2. Ferrite Switch
3. Isolator
4. Mixer - Preamplifier
5. Local Oscillator - (Gunn diode oscillator)
6. IF Amplifier
7. Square Law detector



optical bench procedure for aligning the antennas of the two radiometers. The atmospheric monitor will be operating on all flights and its output will be recorded at all times as well as being available to the pilot.

C) Experiment Controller and Data Logger

The data from the instrument and various monitors is recorded by a Datel LPS-16 cassette incremental tape recorder. One cassette is sufficient to record all data and monitor information from take off until touchdown. The cassette thus generated is read by our Datel reader which with the help of a mini-computer produces a standard computer compatible tape. We already have programs which can then process and display this data for further analysis.

The experiment controller produces the synchronizaton and sequencing of the experiment. The experiment controller thus naturally contains the master clock which will be kept on Greenwich Mean Time and recorded by the data logger.

D) Rotation System

The rotation system for producing physical interchange of the antennas has been completed and tested. Photographs of some of the components and a system schematic are shown on the next pages. Individual components have been vacuum and cold tested; the entire system has been tested for a total of more than twenty hours at STP. The system is designed to interchange the direction the antennas look every 128 seconds. The interchange takes about 6 seconds. The drive accelerates the equipment up to speed, rotates the system, then deaccelerates, ending with a gentle bump against the stop. The alignment is check to be better than  $1/2^{\circ}$  at all times by a microswitch that sends the system creeping back to the stop if it opens. There is also a second monitor which measures the alignment and is recorded on the data logger.

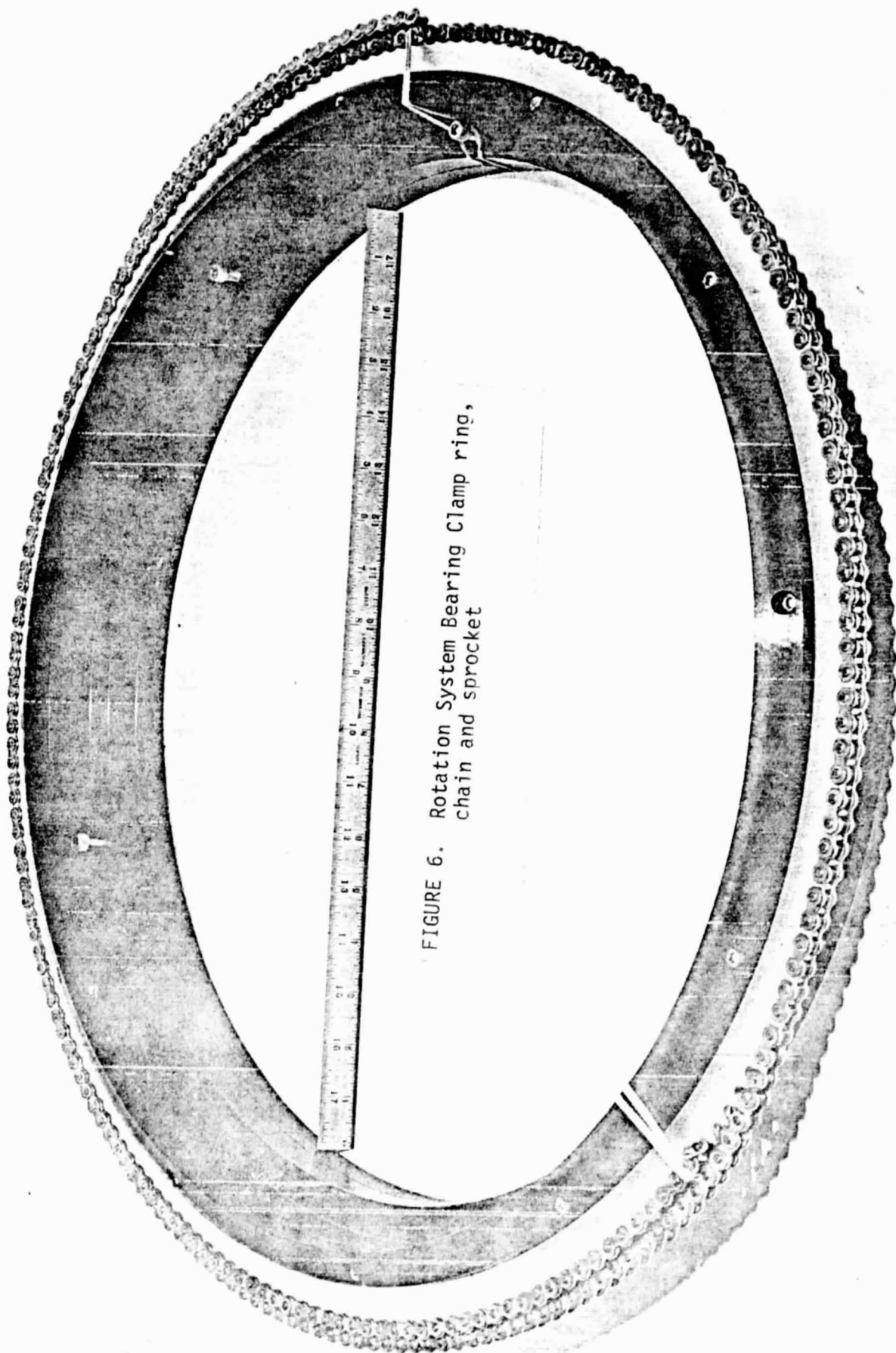
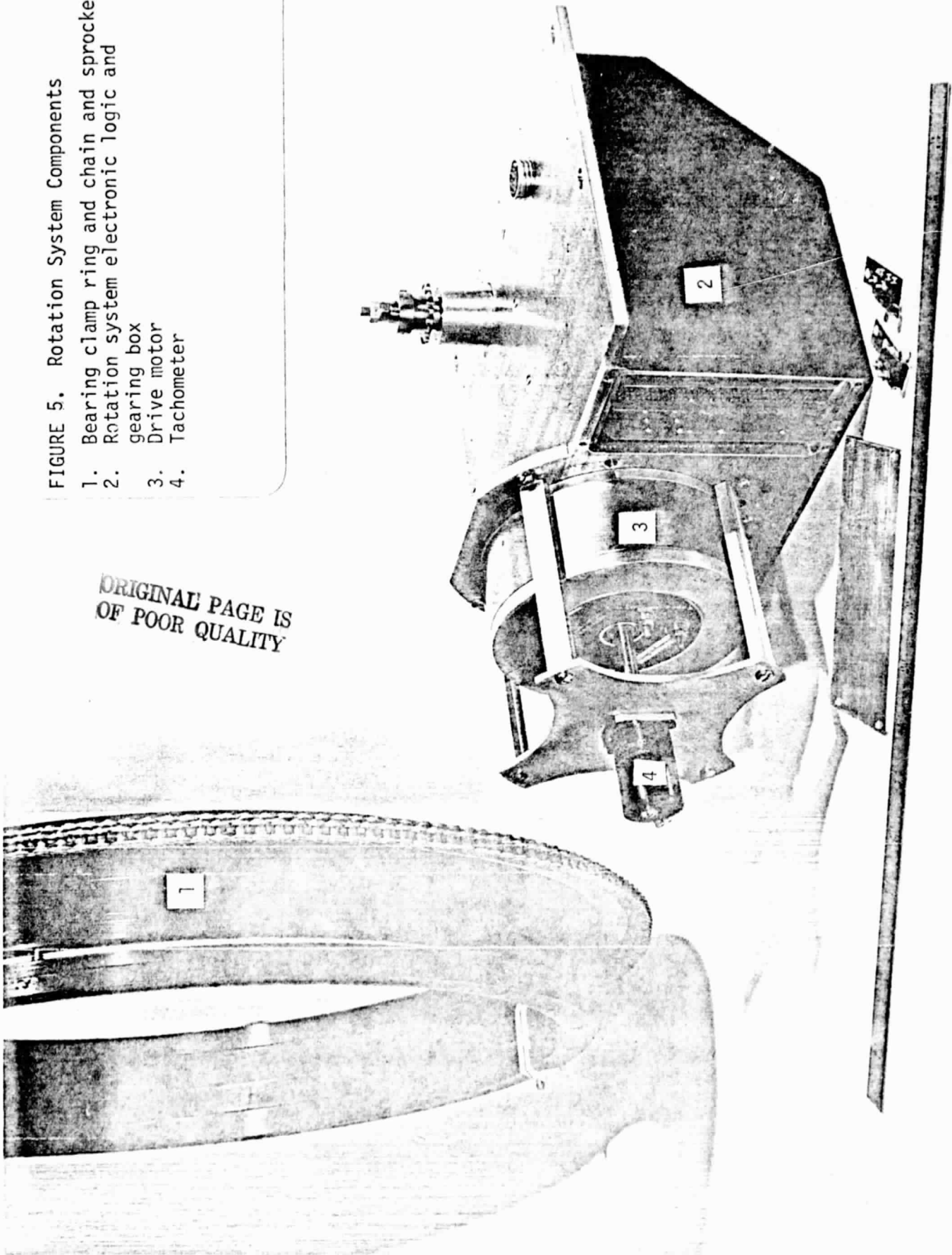


FIGURE 6. Rotation System Bearing Clamp ring,  
chain and sprocket



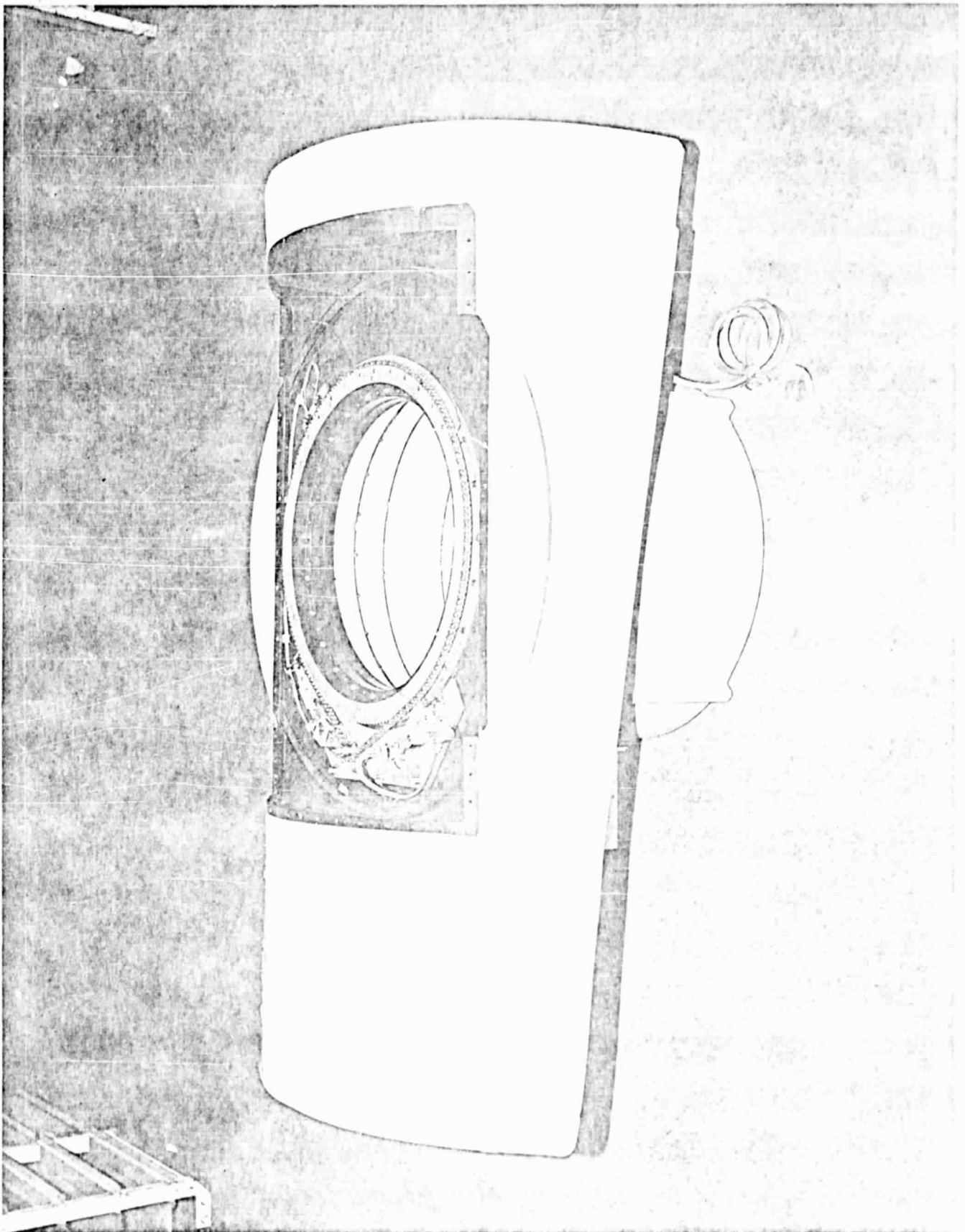
FIGURE 5. Rotation System Components

1. Bearing clamp ring and chain and sprocket
2. Rotation system electronic logic and gearing box
3. Drive motor
4. Tachometer

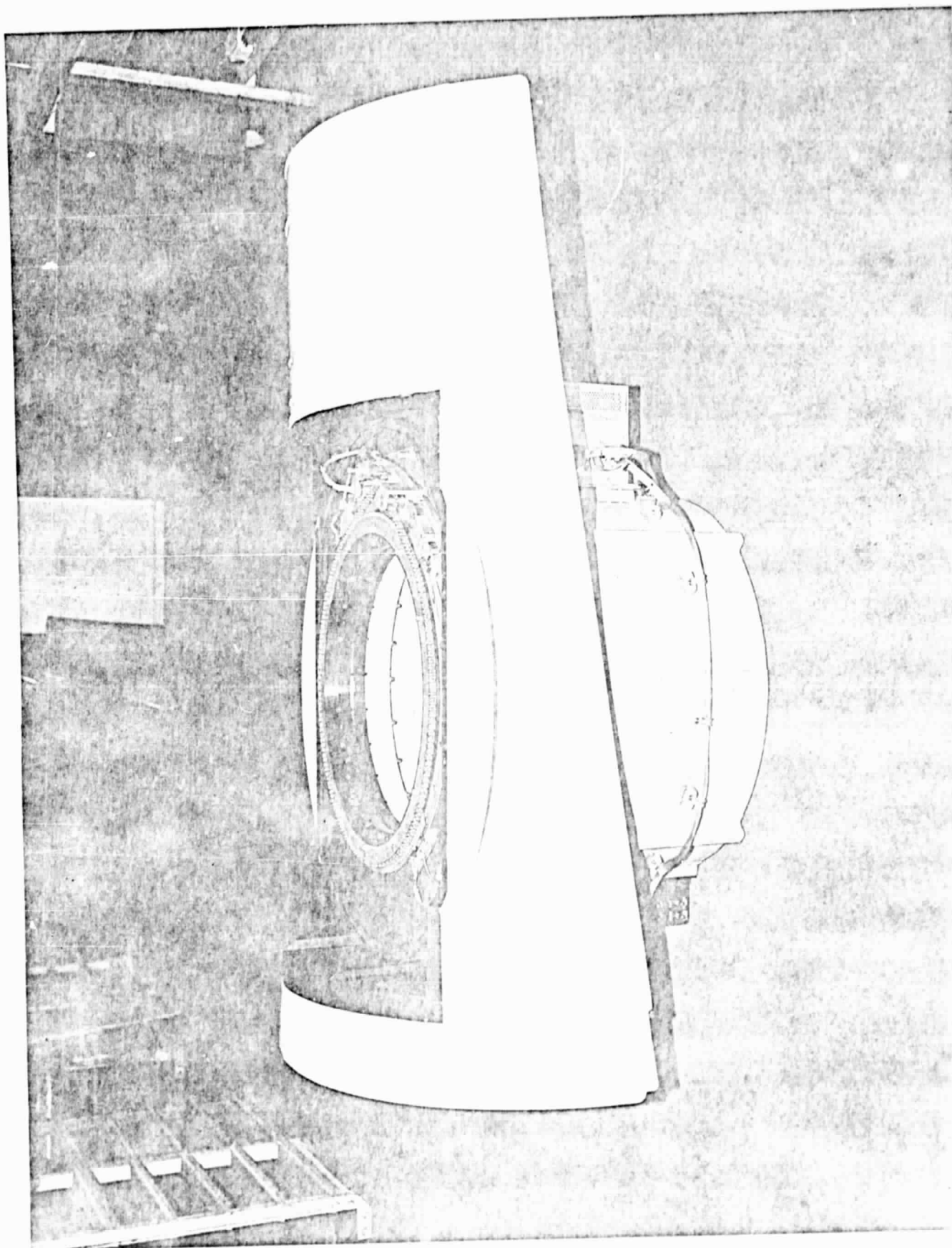


ORIGINAL PAGE IS  
OF POOR QUALITY

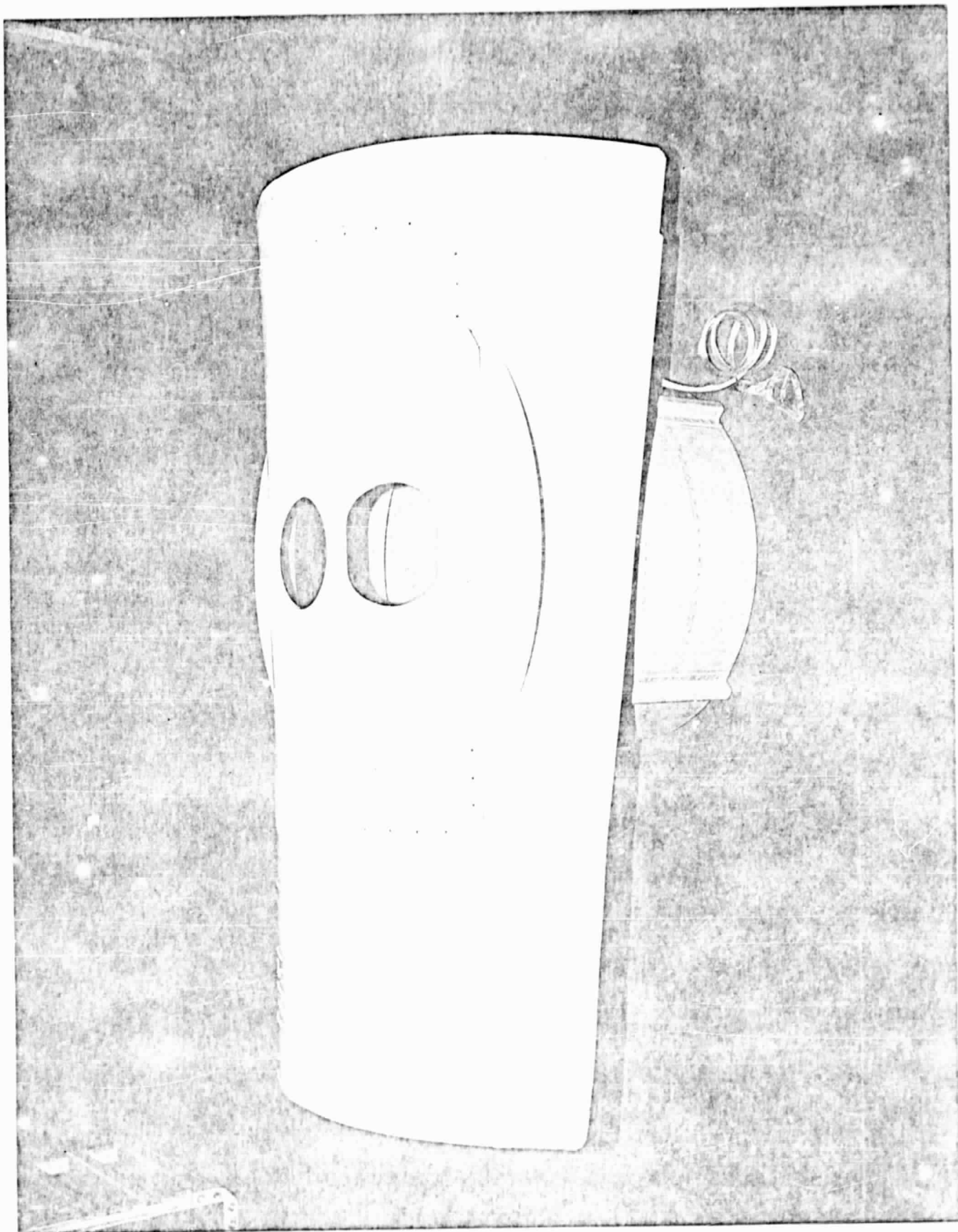




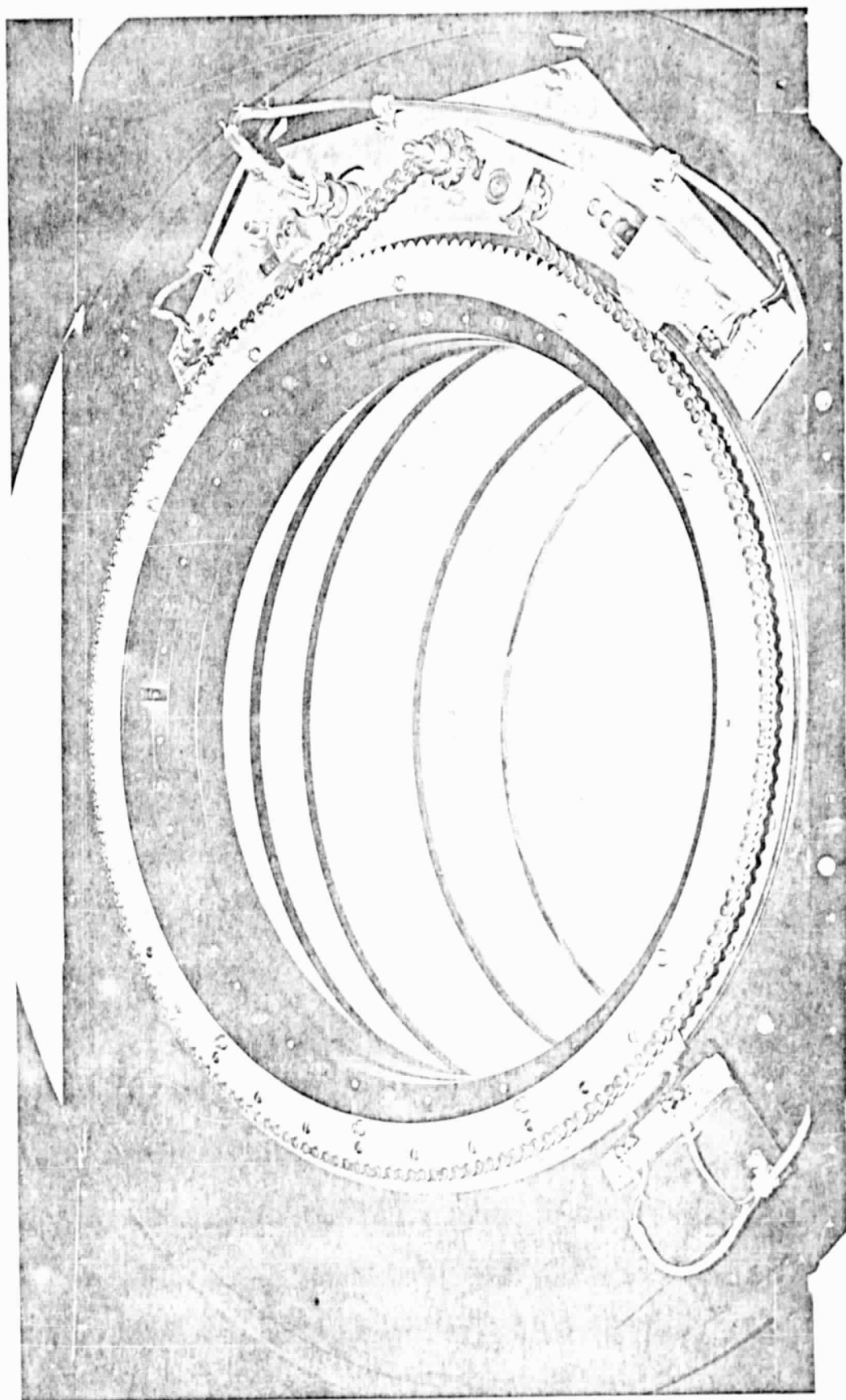
ORIGINAL PAGE IS  
OF POOR QUALITY



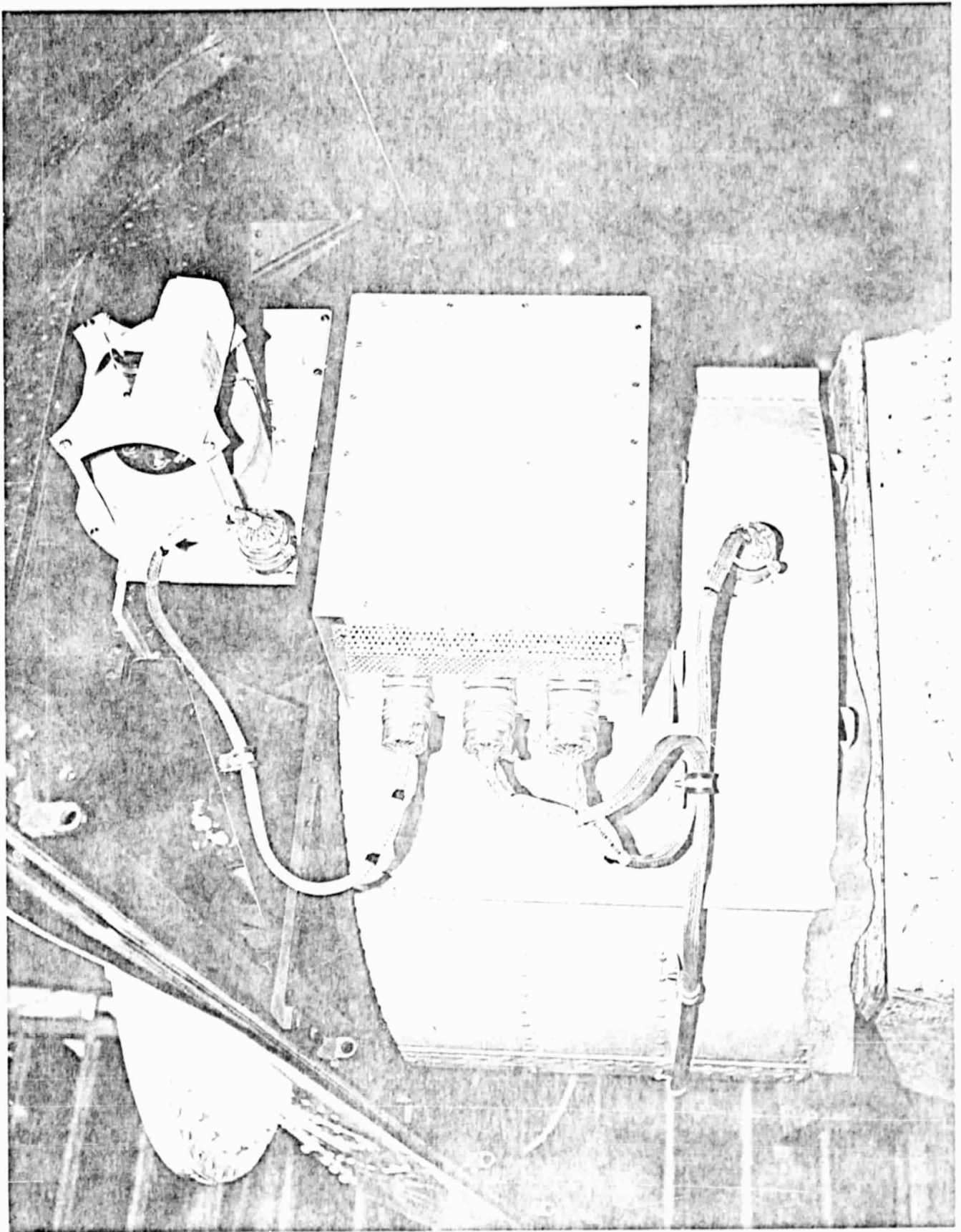
ORIGINAL PAGE IS  
OF POOR QUALITY



ORIGINAL PAGE IS  
OF POOR QUALITY

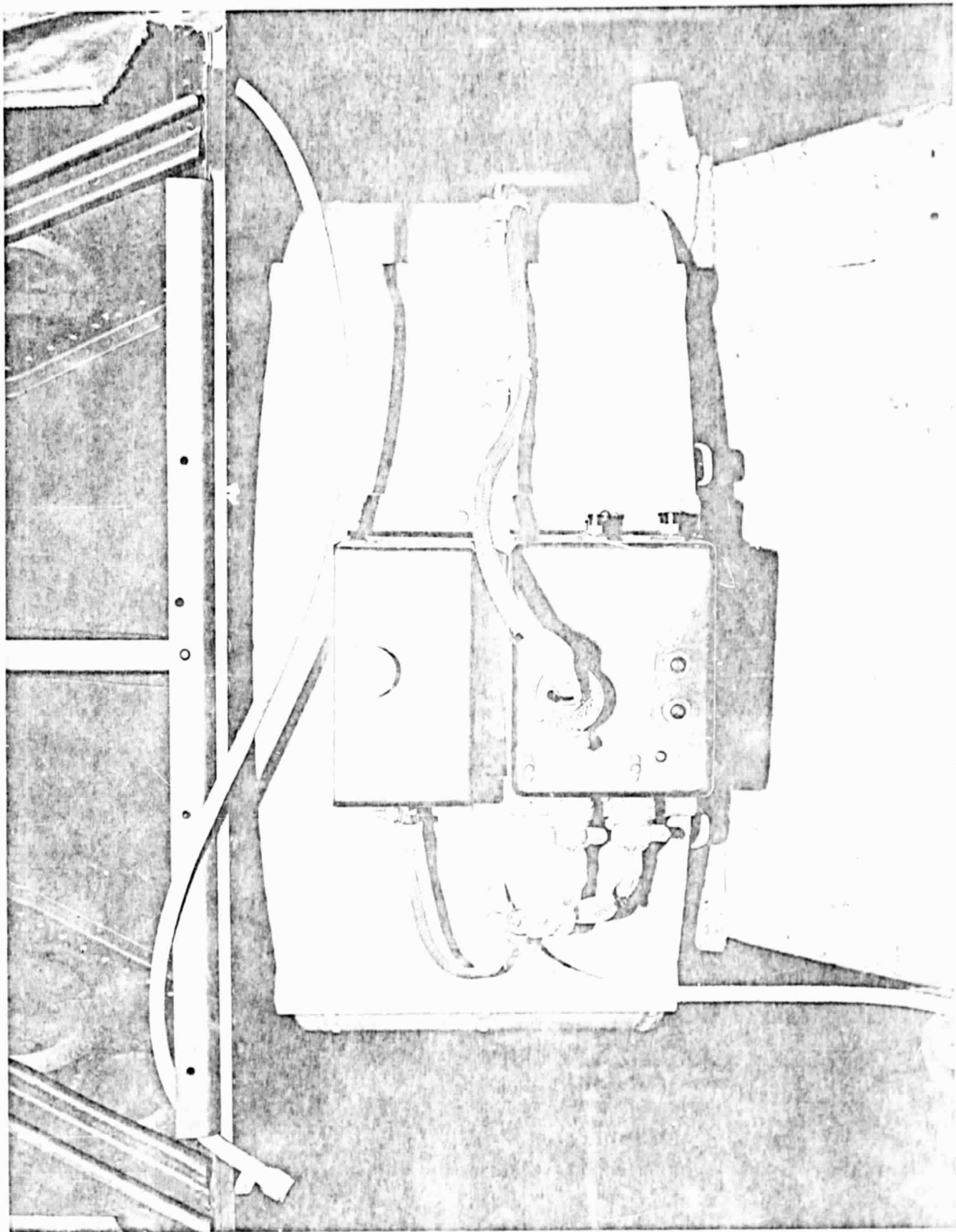


ORIGINAL PAGE IS  
OF POOR QUALITY

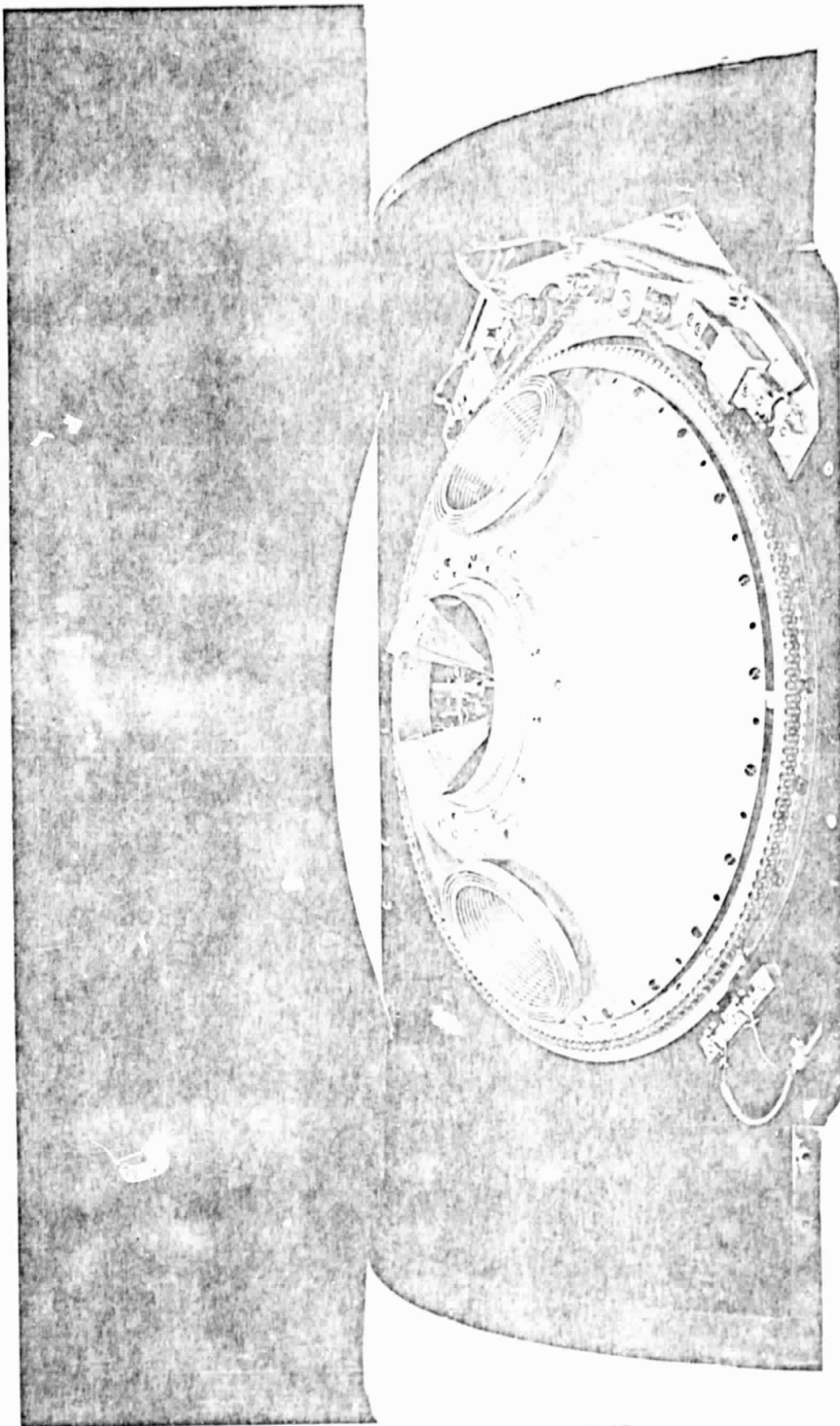


ORIGINAL PAGE IS  
OF POOR QUALITY

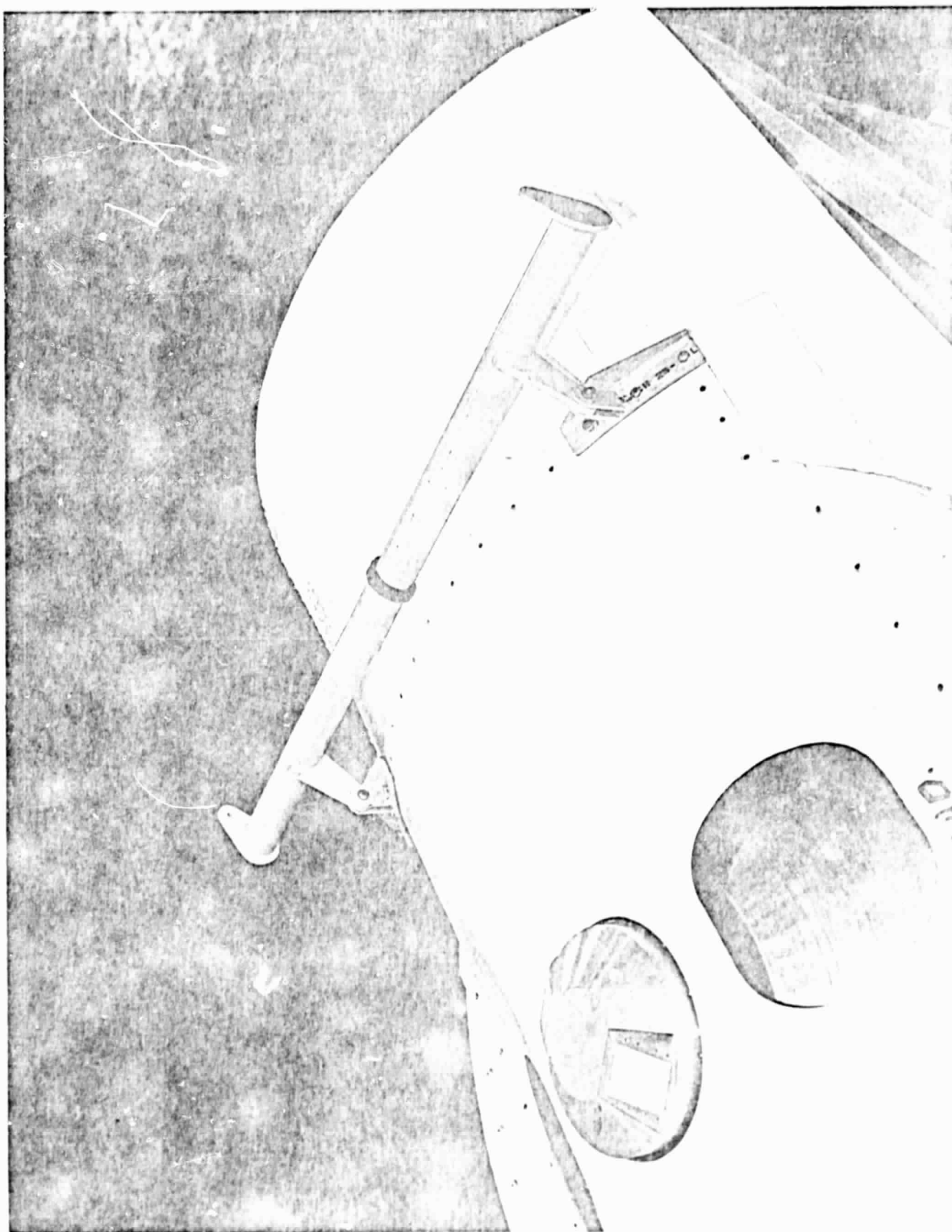




ORIGINAL PAGE IS  
OF POOR QUALITY

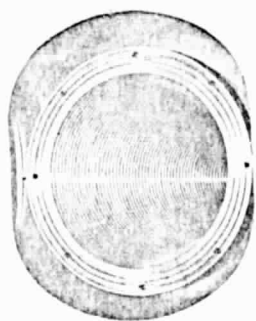
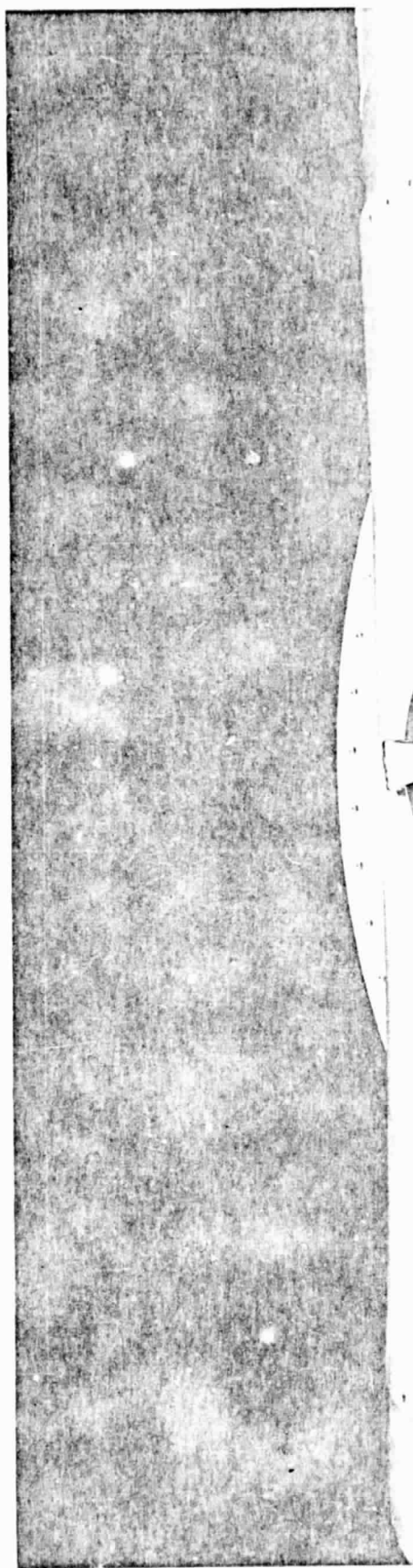


ORIGINAL PAGE IS  
OF POOR QUALITY

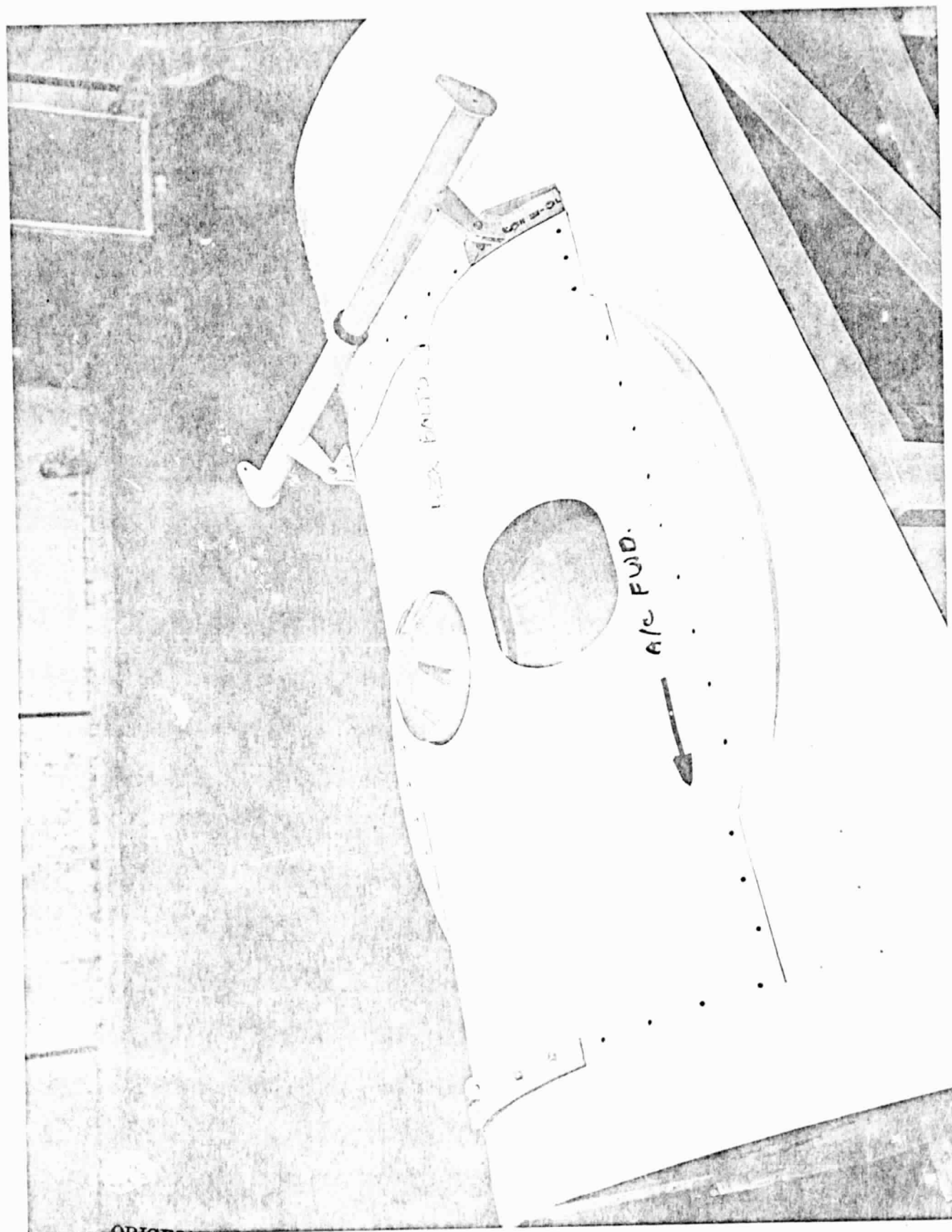


ORIGINAL PAGE IS  
OF POOR QUALITY

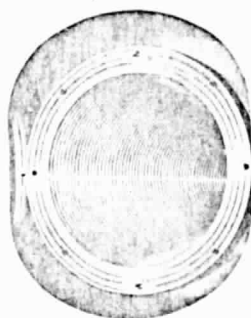
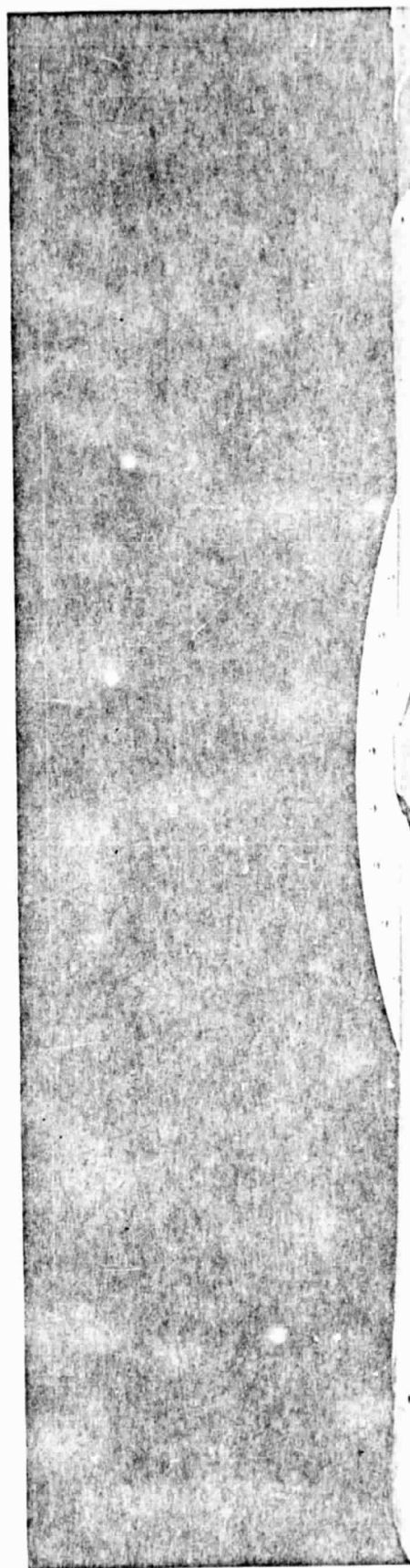




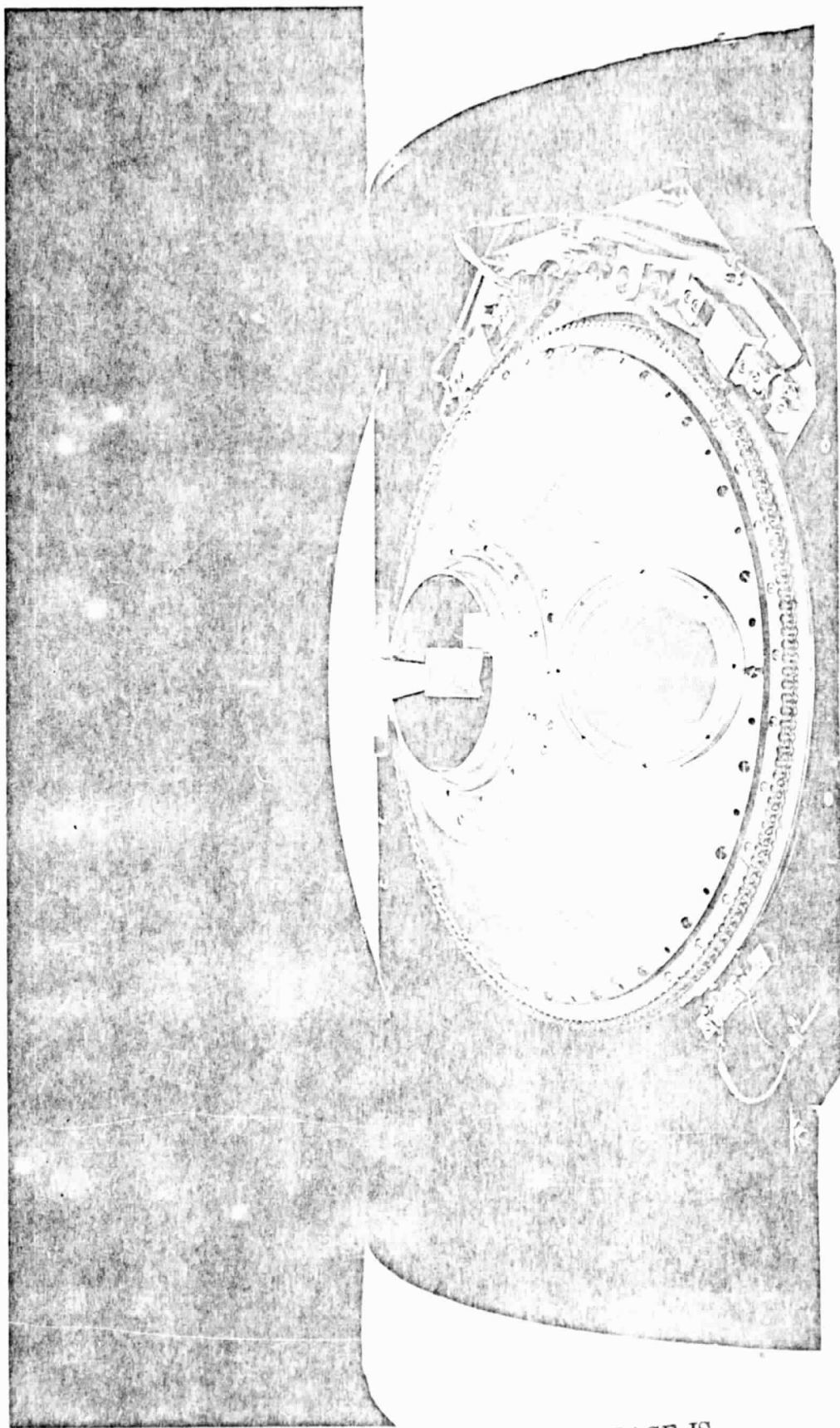
ORIGINAL PAGE IS  
OF POOR QUALITY



ORIGINAL PAGE IS  
OF POOR QUALITY



ORIGINAL PAGE IS  
OF POOR QUALITY



ORIGINAL PAGE IS  
OF POOR QUALITY